Weatherwise

The Weather Bureau's Fire-Weather Service

Weather and Atmospheric Pollution

Open Season on Hurricanes

Opportunities in Naval Aerology

Air Force Postgraduate Weather Training

Vol. 3, No. 5, October, 1950

"SOME PEOPLE ARE WEATHERWISE BUT MOST ARE OTHERWISE" — BENJAMIN FRANKLIN

WEATHERWISE

THE MAGAZINE ABOUT WEATHER

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CAPTAIN MINTER HEADS NAVAL AEROLOGY

The new head of the Naval Aerology Branch, Office of the Deputy Chief of Naval Operations for Air, is Capt. Robert O. Minter, of Martinsville, Va. He succeeds Capt. Howard T. Orville, past president of the American Meteorological Society, who retired from the Navy in June, and is now chief of engineering for the Friez Instrument Division of Bendix Aviation Corporation. Capt. Minter has been an aerological officer for various fleet staffs, and at Naval Air stations and weather centrals from 1932 to 1944. He was officer in charge, Aerological Engineering Curriculum and Group, U. S. Naval Postgraduate School, Annapolis, from 1944 to 1947.

GENERAL SENTER HEADS AIR WEATHER SERVICE

Coincident with his promotion to the rank of general officer, Brig. Gen. William O. Senter, of Abilene, Texas, has been appointed chief of the Air Weather Service, Military Air Transport Service, with headquarters at Andrews Air Force Base, Maryland. He has served as deputy chief of the AWS since July of last year, and succeeds Brig. Gen. Donald N. Yates, who has been transferred to Air Force headquarters. General Senter is recognized as a pioneer in the application of meteorology to military operations. He went overseas in March, 1945, serving in the Philippines and Japan. Before returning to the United States in June, 1948, to attend the Air War College, General Senter served as commanding officer of the 2143rd Air Weather Wing in Tokyo.

Left: Brig. Gen. William O. Senter, new chief of the Air Weather Service.
Right: Capt. Robert O. Minter, new head of the Naval Aerology Branch.

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Cover: Forest fires moving up separate canyons at night, at the Deep Creek fire front, 1940, in San Bernardino National Forest, California. U. S. Forest Service photograph by Fred Funke.

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Meteorology helps protect these timber-clad slopes seen from the Rock City truck trail in Idaho. U. S. Forest Service photograph by K. D. Swan.

The Weather Bureau's Fire-Weather Service

HARRY E. ALTMAN, UNITED STATES WEATHER BUREAU

WEATHER has always been a vital factor in determining the frequency of forest fires and in the efforts required to control them. Dry, hot, or windy weather can cause dangerous conditions to develop in forest areas and on grasslands along highways. During such times a single spark from a cigarette, a pipe, or a neglected campfire may result in the destruction of thousands of acres of natural resources, and cause loss of life, homes, ranches, and wildlife. Equally serious are the indirect damages from fire erosion, loss of top soil, sedimentation of reservoirs and navigable streams, floods, and high costs of lumber and other forest products.

To help solve a serious part of this problem in the Northwest, an appeal was made to the Weather Bureau in 1913 for a study of those weather conditions during which strong east winds had caused devastating forest fires in Washington and Oregon. This study led to arrangements for advance warnings when strong high pressure systems were to cast their "shadows" on the forests.

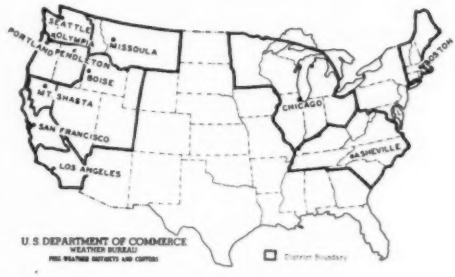
The next step in the development of the fire-weather warning service was daily forecasting for forest areas. This service, although generalized in scope and in content, proved helpful, and other forest regions requested similar forecasts. This resulted in the gradual establishment of 12 fire-weather centers where forecasters concentrated their attention on the weather in the forests.

At the same time, research conducted by forest service experiment stations showed that the chances of a fire starting and the rate of spread in a given fuel and terrain depended primarily upon specific combinations of three weather variables: temperature,

moisture, and wind. In the Northwest, where hundreds of forest fires each year resulted from thunderstorms, lightning frequency was also very important. These elements were integrated into fire danger rating systems, individual systems being developed in regions having differing types of forest fuel. Thus, with the forecasts, the fire danger rating could be determined in advance and action taken to prevent many fires from occurring or spreading rapidly.

Since fire danger ratings could vary widely within a forest unit, information was needed in the forecasts to indicate the changes that would influence the fire danger in local areas, such as ranger districts. The mention of rain or no rain no longer provided enough information, and it became necessary to specify the amount of rain, its duration, and the probable time until the next rainfall.

To furnish this type of forecast, it was necessary to make detailed analyses of weather observations representative of the forest areas. The observations were made at ranger stations, forest guard stations, and lookout towers. Instrumentation at these stations depended upon the fire danger rating system in use. Some stations were equipped with only a rain gage, an anemometer, and fuel moisture sticks. Others had, in addition, maximum and minimum thermometers, a psychrometer and a hygrothermograph. The station analyses made it possible to give synoptic situations, and studies of this nature, along with the development of empirical forecast rules, are now being continued at each fire-weather center.



Fire-weather districts and centers, the district boundaries shown with heavy borders.

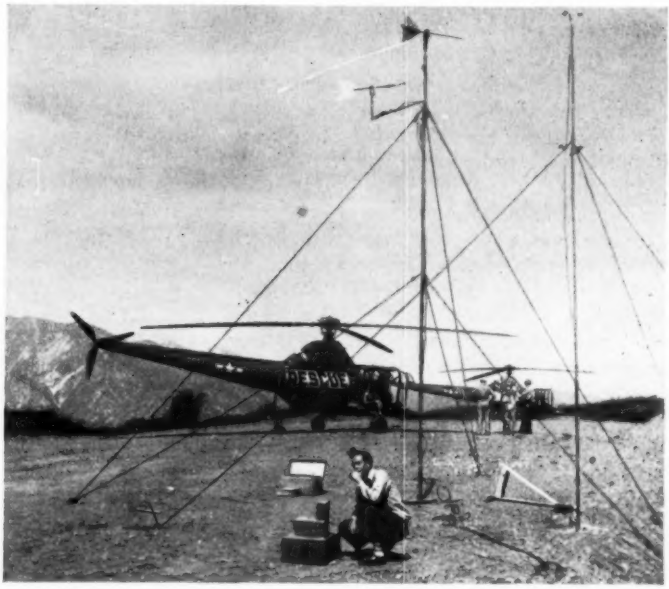
Present-day forecasters try to be thoroughly familiar with the topography of the individual areas for which forecasts are being issued, in order to know how each topographical area will influence the weather. For example, the charts and radiosonde graphs may indicate decreased humidity and sky cover along with increased temperature and wind velocity the following afternoon. An estimate of the amount of change expected must be included in the forecast for each individual area. As for lightning, it must be specified what particular forest lands will be affected and what areas will not be endangered by lightning storms. The amount of precipitation accompanying such storms must be specified.

Diurnal changes are important also. In the absence of a strong pressure gradient or turbulence resulting from intermingling air masses, pronounced upslope winds will usually start to develop by 10 o'clock in the morning and will slowly increase in speed until late afternoon. The amount of this increase determines the rate of spread and resistance to control of a mountain fire, and the number of fire fighters needed. It is also of value to know when in the evening the upslope winds will begin to subside, when

The wasteland that remains in the Tillamook burn, looking east across salvaged logged area up the south fork of the Wilson River, Oregon. U. S. Forest Service photograph by Ray Filloon.

the air will become calm, and when downslope night winds will start. Evening wind shifts depend on the season, the slope of the ground, and the local wind currents created by the fire; the shift to downslope winds tends to occur earlier on north slopes than on south slopes.

When the pressure gradient is sufficiently strong, such diurnal changes of wind direc-



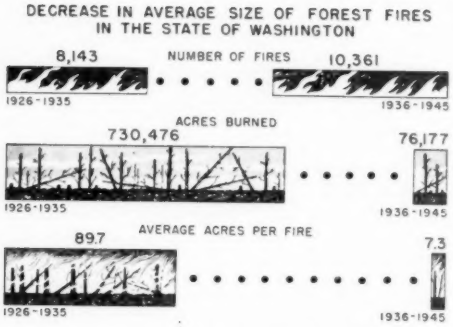
A portable weather installation alongside a truck trail, established as part of a Forest Service, Army, and Weather Bureau cooperative project to determine the practicability of helicopters for landing fire fighters at given elevations. U. S. Forest Service photograph at Lytle Creek Ridge, San Bernardino National Forest, California, 1946.

tion may be modified or entirely eliminated, and a wall of flame that would normally slow down or die during the night would continue its forward march in spite of a nocturnal increase in humidity.

Relative humidity forecasts are vital for fire prevention and for fire control activities. When humidity is high, forest guards and other workers can continue on important improvement projects. With low humidity, preparatory steps must be taken by fire control organizations — the intensity of this preparation is proportional to the danger rating and such factors as the number of days since the last rain.

In the Asheville, N. C., fire-weather district, 36-hour "tailor-made" forecasts are issued for more than 80 separate forest areas. This involves extensive knowledge of local influences, for this district comprises all forest lands from the Ohio River to northern Georgia and the Atlantic Coast. Each forecast includes, for the ranger district concerned, specific estimates of sky cover, amount and kind of precipitation, maximum temperature, minimum fuel moisture, wind direction and speed. These elements are forecast for three separate periods, today, tonight, and tomorrow, with minimum temperature and maximum fuel moisture being included in the nighttime data.

The daily 36-hour forecasts, issued morning and evening by some centers, are used as a basis for making decisions about opening and closing high fire hazard areas to the public, suspending logging operations, issuing burning permits, manning lookout towers, employing aerial reconnaissance, patrolling roads, trails, and railroads, and deploying forestry manpower and equipment. When a forecast is required for prescribed burning operations (a procedure for disease control and tree seed-bed preparation), the areal limits of a successful operation should be known. If the forecaster is aware that winds of more than seven miles per hour in a given fuel will be difficult to control, and winds of less than three miles per hour too light for a successful burn, he is in a better position



to advise operational managers when such burning operations can be conducted. Other special forecasts are issued for slash burning, aerial spraying, smoke-jumper training, and helicopter operations.

Special on-the-spot forecasts are prepared at the scene of large forest fires in the West. Mobile forecasting units are called upon to go to fires at any time of the day or night. At the fire a portable weather station is set up, arrangements are made to secure weather observations from various sectors of the fire line, and weather maps are plotted and analyzed from radio broadcast data transmitted from the fire-weather centers. The forecaster at the fire can correlate fuel types and fire behavior with the current weather situation. His results enable fire control officials to decide when reinforcements will be needed, where men and equipment can be used to best advantage, and the best fire-fighting techniques.

For example, if the wind is expected to cause a change in the direction of travel of the fire, men and equipment can be placed to prevent the fire from escaping. If the usual downslope winds of the night are not going to materialize, plans must be made to reinforce fire fronts that would ordinarily not be extremely active. When high humidity is expected, backfiring operations are not effective and other fire-fighting techniques must be employed.

The importance of the fire-weather service is shown by such statements as this by C. S. Crocker, U. S. Forest Service regional fire control chief, who said:

"On the St. Joe fire, some 900 men were 'highballing' a fire line ahead of a dangerous big fire in a valuable timber area. Tactics were adopted on the basis of normally expected wind conditions which would cause an eastward run by the fire. Most of the manpower was concentrated in preparing a close-up, flanking attack line, since such action would be essential for control under a west wind. A special weather forecast indicated a radical change in wind direction. The unusual — an east wind — was predicted. Forces were shifted and the tactics changed to a scheme of backfire preparation. The wind changed, the lines held, and thousands of dollars of expense were saved. Several hundred fire fighters were released, and large crews of vitally needed lumbermen returned to their jobs days earlier as a result of action made possible by special weather reports."

C. S. Cowan, chief fire warden of the

(Continued on page 118)

A mobile fire-weather forecasting unit at Big Meadows fire camp during the powerline fire that occurred in the fall of 1941 in Yosemite National Park. USWB photograph.

Weather and Atmospheric Pollution

E. WENDELL HEWSON, ROUND HILL FIELD STATION
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CONTAMINATION of the atmosphere by foreign substances comes about in many ways. Here we shall consider the behavior of only those which result directly and immediately from human activities, such as industrial operations.

The turbulence of the wind — as manifested by the irregular air motions (gustiness) which are so noticeable at times — is the most important single weather element in its effect on pollution, since it is the chief mixing agency in the atmosphere. When the wind is markedly turbulent, smoke and fumes will diffuse rapidly. With low turbulence, however, there is little mixing of the smoke with surrounding cleaner air; unless the supply is reduced or the weather changes, offensive or even injurious accumulations of contaminants will develop.

The variations in turbulence are most conveniently considered in their relationship to wind speed and temperature lapse rate. If the air flows rapidly over the earth's surface, most of which is rough, a type of mechanical turbulence is set up. This mechanical turbulence decreases in intensity as the wind speed lessens, becoming very small under calm conditions. With small temperature lapse rates or inversions, the air is stable and turbulent motions of the mechanical type are damped out. However, as the lapse rate increases, this damping becomes progressively less, and with superadiabatic values large and very active eddies develop to produce a field of thermal turbulence. The largest of these eddies are the thermals, of great interest to sailplane pilots, and the cumulonimbus cloud systems, which concern many others. The problem is further complicated by the fact that not only is turbulence dependent on wind speed and on lapse rate, but also the latter two are closely interrelated.

The key to understanding diffusion in the atmosphere is the stability of the air as indicated by its lapse rate. Only a strong wind near the surface promotes turbulence; one at higher levels has no such effect. A stable layer, whatever its position, inhibits turbulence within the layer, and an unstable one promotes turbulence. We can therefore tell a

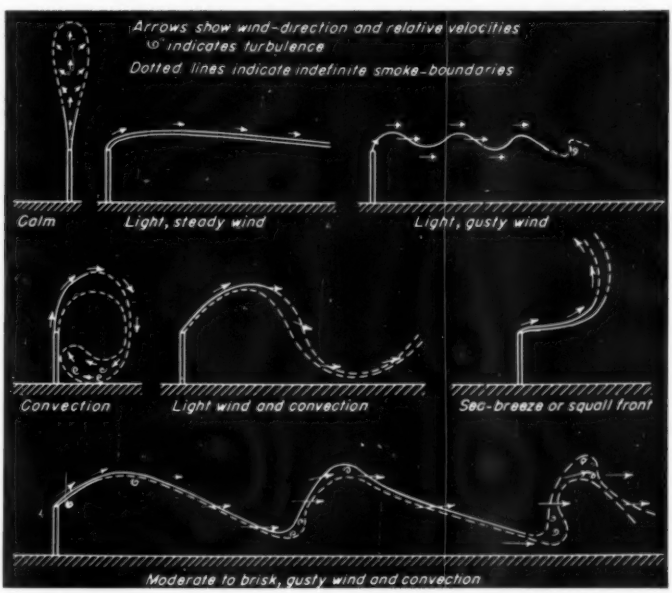


Fig. 1. The behavior of smoke from a stack under various weather conditions, as described by P. W. Etkes and C. F. Brooks.

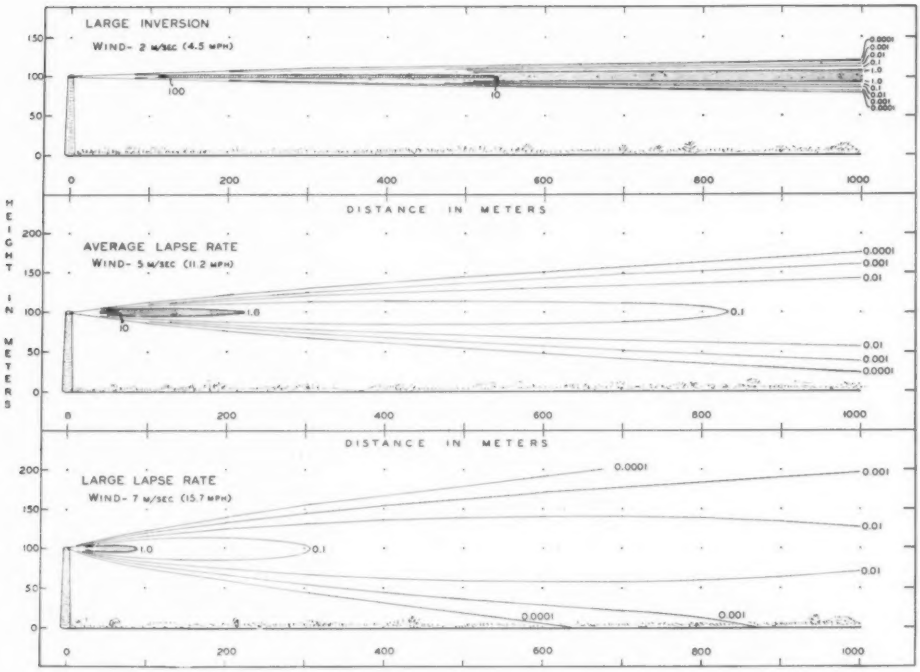


Fig. 2. The theoretical distribution of pollution from a 100-meter stack, as expressed by Sutton's equations. Isolines give concentrations of a contaminant in the vertical plane through the center of the plume in milligrams per cubic meter for a rate of emission of one gram per second. The ground presents a barrier to downward diffusion at the surface, leading to increased concentrations there and, hence, to an asymmetrical distribution in the vertical, as shown in the bottom diagram.

good deal from the vertical distribution of temperature in the first thousand feet or so of the atmosphere. The position of stable and unstable layers relative to the source of fumes or smoke is of prime importance.

With sources at or very close to the earth's surface, the analysis is straightforward and presents little difficulty. With small lapse rates or with inversions near the surface, turbulent mixing is slight, diffusion is slow, and large concentrations of contaminants are to be expected. On the other hand, superadiabatic lapse rates promote rapid diffusion and low concentrations. The picture with an elevated source, such as an industrial stack, is somewhat more complicated (Fig. 1). Consider a shallow, ground-inversion layer whose upper boundary does not extend to the source and a less stable layer above, into which the effluent flows. No smoke or fumes will reach the surface, although it may diffuse down to the top of the inversion layer; the lack of turbulent mixing in the latter prevents downward diffusion of the effluent to the surface.

With an inversion that extends from the ground to above the stack, the smoke flows for many miles at or above the height of the mouth of the stack in a thin but gradually widening band (Fig. 2); no appreciable amount of smoke reaches the surface, even at great distances away. A frontal or subsidence inversion aloft, not far above the top of the stack, accompanied by large lapse rates from the inversion down to the ground, tends to increase smoke concentrations at the ground. Although turbulence may be marked and diffusion good near the surface, the inversion above prevents upward diffusion of the contaminants and confines them to a horizontal layer. As a result, there are higher surface concentrations than in the absence of the inversion aloft. However, in this case, horizontal diffusion is not impaired, and the condition is not therefore likely to lead to

extremely high accumulations at the ground.

There are two weather situations which may lead for brief periods to high ground concentrations of the contaminants from a stack. With light winds and very unstable air, as on a clear summer day, large thermal

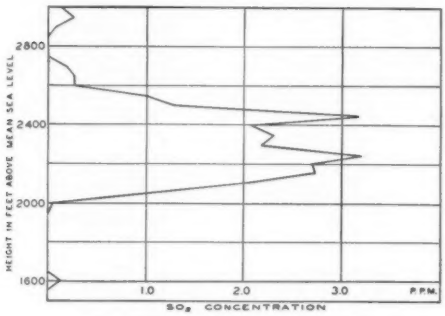


Fig. 3. With inversions and low winds, diffusion is low and stratification of smoke is marked. The vertical distribution of sulfur dioxide (expressed in parts per million parts of air) emitted from the smelter in the Columbia River Valley at Trail, British Columbia, measured about a mile from the stack from 01:35 to 01:50 on May 17, 1940, by E. W. Hewson and G. C. Gill, is shown above. The air was stable and the wind very light, about two miles per hour at 2,400 feet.

eddies may bring down near the stack smoke and fumes in undesirable concentrations. The second situation and development is: Before sunrise on a clear summer morning the smoke flows downwind from the stack in a thin plume which does not reach the ground. After sunrise the sun heats the ground, which in turn heats from the bottom a layer of air, producing in it a superadiabatic lapse rate and hence pronounced turbulence. When the top of this turbulent layer reaches the plume of highly concentrated smoke aloft, the latter is rapidly diffused downward and produces high surface concentrations which occur for about half an hour over the area below the initial plume. In the Columbia River Valley, high surface concentrations of sulfur dioxide from the smelter at Trail, British Columbia, have been found to occur simultaneously between 8 and 9 a.m. over an area extending more than 30 miles down-valley from the smelter.

Up to this point, we have been discussing only the pollution from a single source, such as an industrial stack. Less detailed information is available about the behavior of pollution from a group of many individual sources, such as found in a large city. One of the most complete investigations, from a meteorological point of view, was that made in and near the industrial city of Leicester, England. It was found that the relative distribution of surface pollution varies very little with wind speed, the position of the center of maximum concentration of surface smoke being never more than half a mile from the center of the city (Fig. 4). In cities, air pollution near the surface also varies with atmospheric stability in the lower levels, concentrations increasing as the air becomes more stable. It is not yet clear whether rain has a significant cleansing action by washing impurities out of the atmosphere.

Not only does the weather affect the degree

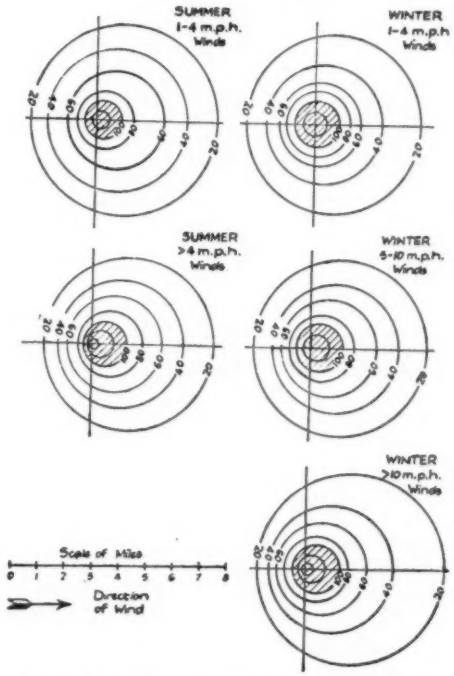


Fig. 4. The effect of wind on urban pollution near street level on days of average weather, as found at Leicester, England. Isolines show relative amounts of native Leicester smoke, the mean for the center of the city being taken as 100. As the wind speed increases, the isolines move downwind by distances as much as one mile, without altering their radii, but there is no significant corresponding downwind shift of the point of maximum concentration.

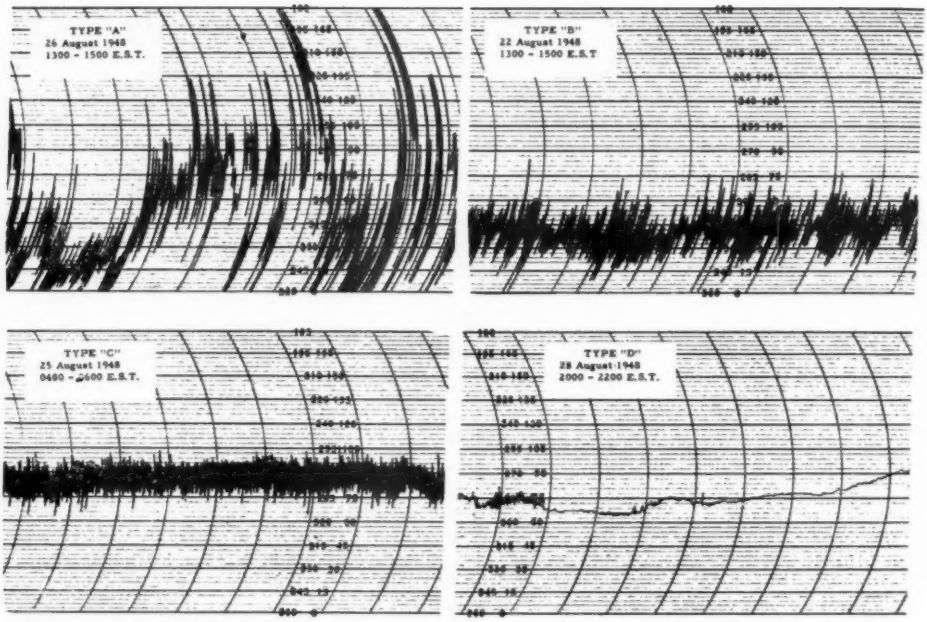


Fig. 5. The four types of gustiness described by M. E. Smith are here specified by a recording wind vane at a height of 355 feet at Brookhaven National Laboratory. "A" shows marked thermal turbulence in unstable air, as on a clear summer day with light winds. "B" results from mechanical turbulence, produced as air flows over rough ground, combined with thermal turbulence, as on a clear, windy summer day. "C" represents mechanical turbulence alone, as found during an overcast, windy night. "D" shows little turbulence of any type, characteristic of clear, calm nights.

and distribution of pollution, but pollution also affects the weather. Climatological studies of rainfall at Rochdale, England, indicate that there is slightly less precipitation on Sundays, when the factories are closed, than on other days of the week. It is inferred that the abundance of condensation nuclei resulting from industrial processes causes slightly more rain on the work days of the week. The Ruhr region of Germany gets measurable rain or drizzle on 20 more days per annum than do nearby less industrialized areas. Laboratory experiments have confirmed other evidence that pollution greatly enhances the persistence of fog and increases its density, although to a lesser degree. In Prague, Czechoslovakia, fogs have been nearly twice as frequent since 1880 as they were between 1800 and 1880. At least part of this increase is undoubtedly due to increased atmospheric pollution.

The topography of the land has a pronounced influence on the severity of pollution. A source in a valley may produce high concentrations under stagnant atmospheric conditions because the valley sides present a physical barrier to lateral diffusion. During persistent weak anticyclonic conditions early in December, 1930, 63 people died in the Meuse River Valley in Belgium as a result of an accumulation of pollution from the industrial city of Liege and nearby towns. Under similar weather conditions, a large accumulation of pollution occurred in the Monongahela River Valley near Donora, Pennsylvania, during the last week of October, 1948, when 20 persons died (see WEATHERWISE, June, 1949).

Pollution of the atmosphere can be minimized in a number of ways. Plant processes may be changed so as to eliminate the production of air pollutants, or equipment such as precipitators, collectors, scrubbers, may be installed to remove impurities from flue gases and other sources. High stacks are helpful in alleviating industrial pollution.

Hot flue gases are an additional aid, especially during light winds, when the buoyancy of the gases causes them to rise for considerable distances above the mouth of the stack.

When plant operations permit, the development of high surface concentrations can be prevented by varying the rate of emission of contaminants in accordance with weather conditions, actual or forecast. In order to prevent damage to vegetation in the State of Washington by sulfur dioxide from the smelter at Trail, British Columbia, an international tribunal set up by the governments of Canada and the United States established a regime for the emission of this gas. Maximum allowable rates of emission are specified in accordance with the prevailing wind direction, speed, and turbulence, the last as measured by a gust accelerometer. The rates also vary with the time of day and season of the year, and overriding rules are provided as safeguards.

A different approach to a similar problem is being employed at Brookhaven National Laboratory (see WEATHERWISE, October, 1948). The emission of radioactive argon from the nuclear reactor there is being varied in accordance with forecast atmospheric diffusion conditions. For forecasting purposes, four types of gustiness have been defined (Fig. 5); cumulative radiation dosage at the ground is predicted on the basis of anticipated wind speed and gustiness. A system of predicting the occurrence of smog in the Los Angeles area has been developed for possible use in controlling the emission of contaminants. The system includes a smog index based on meteorological quantities, and a chart which uses upper winds and pressures to aid in forecasting smog-free days. Finally, as a result of the Donora disaster, it has been recommended that the industries in the Donora area curtail production when a stagnant valley-air condition develops and persists.

Potential pollution problems can sometimes be avoided by the use of climatological and microclimatological data when the location of new industrial plants is being decided. Because of features of the terrain, two possible plant sites, only a few miles apart, may have dissimilar dispersion characteristics, and the right choice of site may prevent air pollution. Here is an opportunity for city planning commissions to render a public service by encouraging municipal governments to undertake and use the necessary microclimatic surveys.

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STORM COMPOSITES BY RADAR

New techniques giving instantaneous and more accurate spotting of hurricanes and other storm areas are now being developed by the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey. Army scientists are using a pair of recently designed radar sets to co-ordinate for the first time long-range pictures of storms passing between strategically located radar weather stations.

Each station takes a radar picture of the storm from a different angle. Combined, these photographs give a truer picture of the contours, direction of movement, precipitation, and other features of the disturbance than is possible with single-station pictures. A single station gets a detailed picture only of the nearer side of a storm; thus a station on the other side of the storm is needed to reveal more about the storm's true boundaries.

This new technique may lead to the establishment of a nation-wide network of radar weather stations. The benefits to storm navigation by planes and ships would be numerous. Co-operating in this research are the Evans Signal Laboratories in Belmar, New Jersey, where the new radar sets were developed, and Massachusetts Institute of Technology.

Open Season on Hurricanes

D. C. CAMERON

HURRICANE HUNTERS had an unusually active five weeks from about mid-August to mid-September, that period producing no less than six fully developed storms. Two of them brushed close to Cape Hatteras and Nantucket, two crossed the east Gulf Coast of the United States, while the other two ran their courses well at sea, beyond Bermuda. The storm tracks are shown on the accompanying chart.

Storm I — August 13-21: This developed northeast of Puerto Rico on the 13th of August, started a turn toward the north but recurved to the west, threatening the Bahamas. However, it turned well to the north and passed within 100 miles of Hatteras, but wind gusts there barely reached whole gale force from the northwest. It was still a severe storm when it crossed Nova Scotia and Cape Breton Island on the 21st, where it caused considerable damage.

Storm II — August 21-31: Found first as a small disturbance east of Antigua on August 21st, this storm crossed the Lesser Antilles near that island, giving it a fairly stiff blow (but mild compared to the one of August 31-September 1). Then it melted away in the Caribbean in an "easterly wave" type of storm, which progressed westward through the Greater Antilles, finally reforming a hurricane core just south of western Cuba on August 26th. Much of western Cuba took a severe beating from this storm as it crossed the western tip of the island into the Gulf of Mexico.

This hurricane entered the United States over Mobile Bay on the night of August 30th. The highest wind reported was 100 miles an hour at Santa Rosa Island, south of Pensacola, but the greatest damage was farther east, at Panama City. There a combination of heavy rain (storm total 14.96 inches), high tide, heavy seas, and whole gales, caused considerable destruction. At Apalachicola a tornado ripped through the residential section late in the afternoon of the 30th. The storm was still severe enough over inland Alabama to blow down several hundred trees in the Birmingham-Tuscaloosa area, and heavy rains caused some flooding.

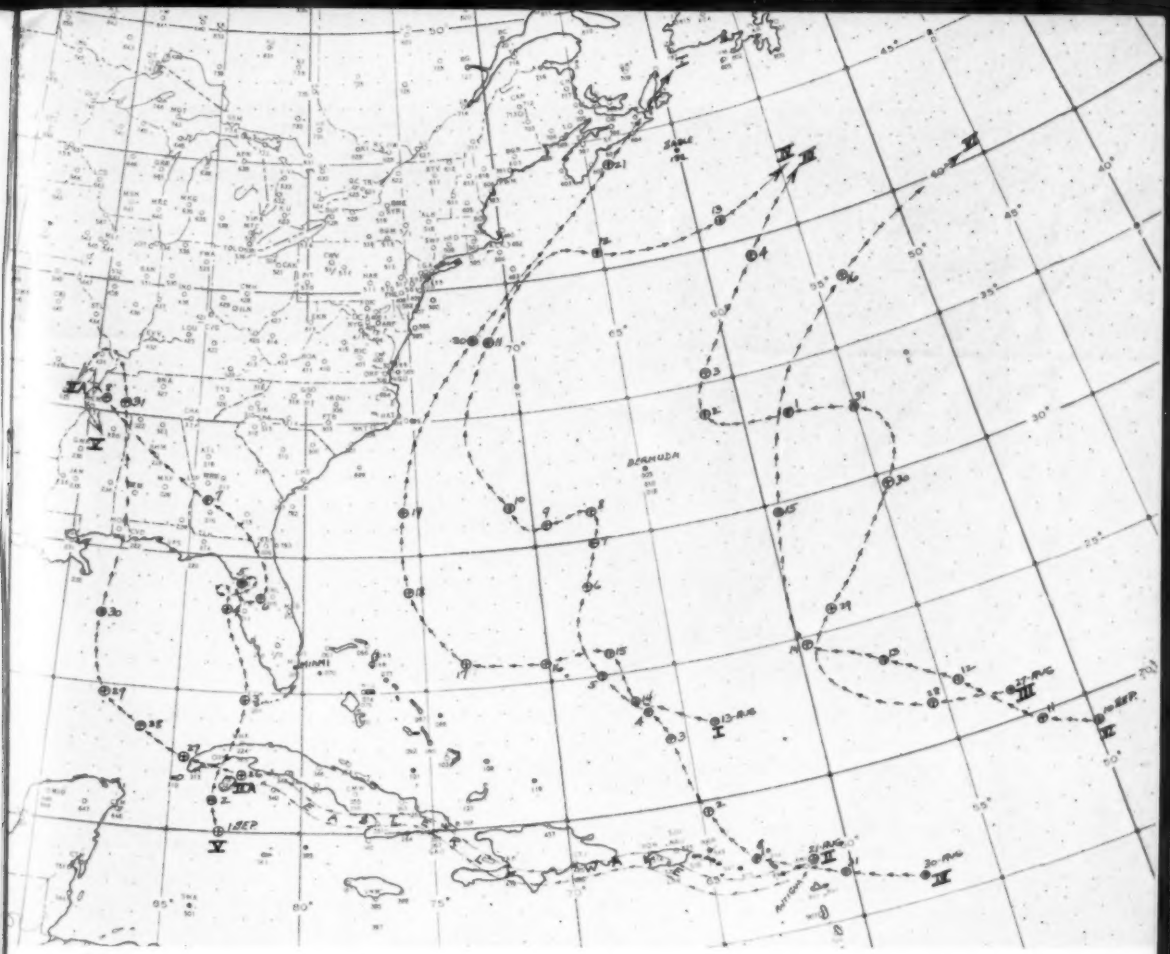
Storm III — August 27-September 4: One of the hurricanes that remained well at sea throughout its course, this storm did recurve toward Bermuda after having made its first turn toward the northeast. It finally headed out into the North Atlantic Ocean.

Storm IV — August 30-September 13: This severe circulation was on the weather map for over two weeks, during which some 50 advisories were issued. First sighted on the 30th of August, it was particularly destructive over the islands on the outer bulge of the Lesser Antilles, worst at Antigua and Barbuda. At Antigua, the PAA anemometer registered 144 miles per hour during the night of the 31st and then blew away; estimates placed the peak near 160 miles per hour and the pressure fell to 28.72 inches. Damage was extensive but no lives were lost at Antigua. Belated reports (September 12th) told of more complete devastation on the outer island of Barbuda, with some 1,000 persons homeless, but meteorological details are not available.

Northeast of Puerto Rico, this storm seemed headed north-northeast, but it veered off to the northwest and started another, more definite turn toward Bermuda on the 5th. The islands were definitely in the path of this huge storm, but an unusually strong high that came off the North American continent on September 6-7 stopped the storm's progress some 150 miles southwest of Bermuda. It started off again toward the west, finally making the customary northeast recurve on the 10th and 11th. It brushed close enough to the southeast New England coast to raise tides, seas, and wind to destructive heights, worst in the Cape Cod-Nantucket area. Nantucket had sustained winds of 55 to 60 miles per hour, during the night of September 10-11.

Another high shunted the storm to the east, and it missed Nova Scotia almost entirely.

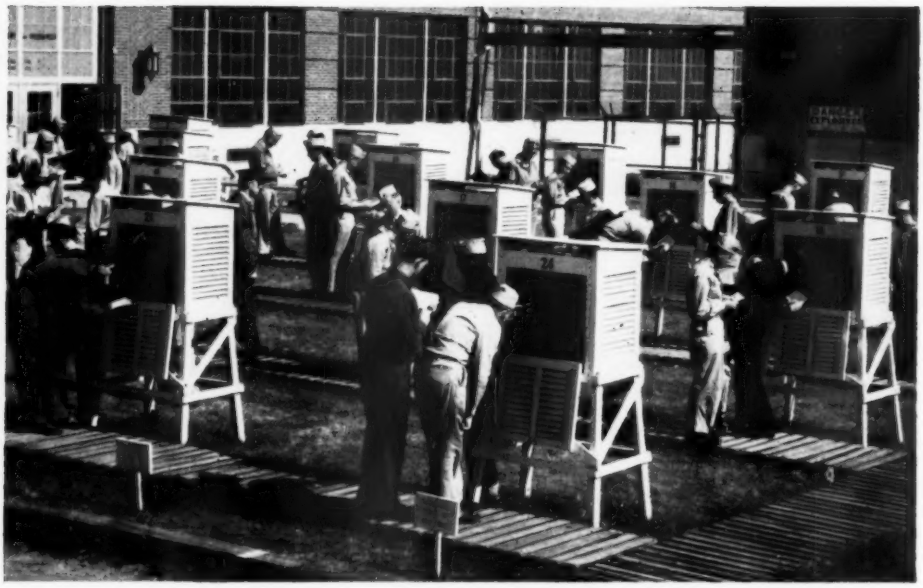
Storm V — September 1-8: This was a relatively mild development south of the Isle



The tracks of the first six hurricanes of 1950, numbered in order of their first appearance. The dated locations indicate storm positions approximately at midday.

of Pines on September 1st, which crossed Cuba during the next night and did some damage there. The storm passed just to the west of Key West about noon on the 3rd, with maximum wind 72 miles per hour and lowest pressure 1000 millibars. It was christened the "baby" hurricane, and it continued relatively moderate up the west coast of Florida, until it slowed down almost to a walk northwest of Tampa and St. Petersburg on the 4th. It made a loop off Crystal Bay and then headed inland toward Ocala on the night of September 4-5. By this time it was a tightly wound little hurricane, and a section of Florida not usually subject to severe hurricanes received the worst storm in its history on the 5th. Cedar Key suffered a full day of hurricane winds, during which an anemometer registering 125 miles per hour was carried down by a falling tree. The 24-inch Weather Bureau standard rain gage filled and ran over, but later squalls added another 1.20 inches, bringing the storm's total to more than 25.20 inches. Ninety per cent of the structures in Cedar Key were damaged, and it was probably fortunate that this storm traversed such a sparsely settled section. Preliminary estimates of damage ran to about 3½ million dollars. The storm center looped back into the Gulf on the 5th and re-entered the state near Homosassa Springs on the night of the 5-6, curving northward again over interior Florida, and

(Continued on page 118)



The training of weather observers at Chanute Field, Illinois. USAF photograph.

AIR FORCE POSTGRADUATE WEATHER TRAINING

A PROGRAM has been established by the Air Force for training a selected number of meteorologists. It is a continuing program with the first class having started in September of this year. Acceptable candidates must be recent Air ROTC graduates who have the proper educational background and qualifications. The planned program will permit graduate study at one of the civilian educational institutions that offers a meteorological curriculum at graduate level, namely, Massachusetts Institute of Technology, New York University, the University of Chicago, and the University of California at Los Angeles. The requirement for acceptance is a degree in physics, chemistry, mathematics, meteorology, or engineering, or that the applicant be a college graduate with a major in one of the physical sciences.

Selected applicants will be called to active duty in the grade of 2nd lieutenant and sent to graduate training at government expense for one calendar year (three semesters). Full pay with allowances for rations and quarters will be received while training. The course of studies will be the same as is offered other graduate meteorological students at these universities.

Upon successful completion of the course, participants will be required to serve as forecasters with the Air Weather Service of the Air Force for a minimum period of three years. Those who did not receive regular commissions by having been honor Air ROTC graduates may compete for them upon graduation, if they so desire. Upon completion of the three-year tour, officers may continue on active duty with the Air Weather Service, be assigned to related Air Force activities including flying school, or become civilians.

Further information about this training may be obtained by writing Chief, Air Weather Service, Andrews Air Force Base, Washington 25, D. C. Persons wishing to submit an application for training should forward an official transcript of college credits, plus two copies of AF Form 125, "Application for Extended Active Duty with the United States Air Force," to the above address. Air ROTC students should forward their applications through the professor of air science and tactics at their colleges.

OPPORTUNITIES IN NAVAL AEROLOGY

TO MAN the weather units aboard the ships and stations of the United States Navy, weather personnel in enlisted rates and commissioned officer status are needed. The enlisted aerographer's mates complete the team with the aerological officers, also called aerologists, in providing weather advice and forecasts for naval operations and planning.

The aerographer's mates make visual and instrument weather observations, prepare weather maps, and make forecasts for use by ships and aircraft. Instruments used in making weather observations include: barometers, thermometers, hydrographs, anemometers, and ceilometers. The teletypewriter, which has a special keyboard of weather symbols, is used for exchanging weather reports and forecasts between shore-based activities of the military services and the United States Weather Bureau. Enlisted men in aerology serve on aircraft carriers, battleships, amphibious flag ships, cruisers, and auxiliary vessels at sea. Ashore they are assigned to Naval Air stations, Navy and Fleet weather centrals and overseas bases.

Aerological officers perform meteorological duties, including map analysis and forecasting, and supervise the operation of the aerological unit. They serve aboard aircraft carriers, flag ships, and the shore stations mentioned above.

In addition to the Regular Navy ships and activities there are 21 Naval Air Reserve stations having active duty weather personnel. At all of these, plus six Naval Air Reserve training units, inactive duty reserve personnel participate in weekend training, with four days Navy pay per month while continuing school or civilian work as desired.

Men or women desiring to be aerographer's mates must be high school graduates. Upon entering the Regular Navy all personnel are sent to a recruit training center for 14 weeks of indoctrination, basic training, guidance, and classification. Following this "boot" training, selected candidates attend the airman's school operated by the Naval Air technical training command aboard the Naval Air station at Memphis for an eight-week course.

Just as for the airman's school, individual aptitude, academic background, achievement in previous training, and personal desires determine the candidates who will be sent to the 14 weeks primary aerographer's mates school at the Naval Air station at Lakehurst, New Jersey. Obviously, any experience or academic training in meteorology or related subjects, such as the physical sciences or

The Navy's "flying classroom" provides aerology students with opportunities to make first-hand observations of weather conditions while experiencing the weather hazards common to navigation through the air. U. S. Navy photograph.

geography, will be helpful. Experience in clerical work also will prove valuable.

The primary aerographer's mates school provides training in meteorological instruments, meteorological weather codes, adiabatic charts, upper-air and balloon soundings, weather and cloud observations, map analyses, typewriting, practical work in the preparation of charts, and use and maintenance of instruments. One interesting phase of the training at Lakehurst is the "flying classroom," in which the aerographer's mates fly to observe the weather elements in action.

In addition to the primary aerographer's mates school, commonly known in naval circles as the "A" school, the Navy has two advanced schools for its enlisted weather personnel. These are called the "B" and "C" schools for aerographer's mates. The "B" school trains petty officers for 16 weeks. The "C" school, which is for chief aerographer's mates, also runs for 16 weeks. All of these schools are under the Naval Air technical training command and are physically located aboard the Naval Air station at Lakehurst, New Jersey. Active duty personnel in the Naval Reserve training program as well as Regular Navy personnel may attend these schools.

Enlisted men and women in aerology may advance through the enlisted rate structure to chief aerographer's mate. Also, for those who are outstanding in their work and possess unusual qualities of leadership, there is the opportunity for further advancement to warrant officer or limited duty officer (LDO) commissioned status.

Most of the Regular Navy aerological officers are graduates of the U. S. Naval Academy who have completed the naval postgraduate school course in aerological engineering. After graduation from Annapolis and experience with the operating forces, selected officers go to postgraduate aerology training at Monterey, California. Other USN aerologists are those who were promoted from enlisted status or transferred from the Naval Reserve at the end of World War II, after coming from civilian life to wartime training and experience. A limited number of Naval Reserve aerologists are on active duty in the Reserve training program.

The Navy is currently interested in commissioning qualified personnel as aerologists in the Naval Reserve. These reservists can remain on inactive duty pursuing a civilian occupation, but must be ready to assume their rightful place in the military establishment in time of possible national emergency. To be commissioned as a qualified aerological officer, one must have a bachelor's degree with major in meteorology, a bachelor's degree with major in a field related to meteorology plus at least one year of postgraduate training in meteorology, or a bachelor's degree with major in a field related to meteorology plus qualifying professional meteorological experience. Candidates possessing lesser qualifications but having a bachelor's degree in mathematics, physics, or chemistry, including at least 14 semester hours in meteorology, may be commissioned and placed in an "in-training" status in the Reserve training program.

It is the basic policy of the Navy to rotate its personnel between sea or advanced base duties and assignment within the continental limits of the United States.

Naval aerology offers the advantages of pay, health services, security and retirement benefits, and travel opportunities common to other branches of the Naval service. The training and experience received in Naval aerology have made the difference in providing the necessary qualifications for many people to obtain desired positions in civilian life following their retirement from the Navy.

AMS MEETINGS IN FLORIDA AND NEW YORK CITY

The next meeting of the American Meteorological Society will be held in Tallahassee, Florida, December 5-7, 1950, with Florida State University as host. Professor Werner A. Baum, editor of the *Journal of Meteorology* and chairman of the meteorology department of Florida State, has arranged a most interesting program.

The 109th national meeting and 31st annual business meeting of the society is scheduled for New York City, January 30-February 1, 1951. Further information concerning these meetings and membership in the American Meteorological Society may be obtained from the executive secretary, Kenneth C. Spengler, 3 Joy Street, Boston 8, Massachusetts.

FORECASTING THE WEATHER

The Relationship of Temperature and Precipitation over the United States to the Circulation Aloft

DONALD E. MARTIN AND HARRY F. HAWKINS, JR.
EXTENDED FORECAST SECTION, UNITED STATES WEATHER BUREAU

STUDIES OF WINTER PRECIPITATION

THE preceding article discussed in general terms the physical aspects of precipitation and explained that the indications of moisture availability and vertical motion are the meteorologist's main concern in making precipitation forecasts. An evaluation of some of these factors from previous research by Smith and Klein was then presented. It was also pointed out that the principal findings of these studies are now applied at the Extended Forecast Section of the Weather Bureau, although in a qualitative fashion. This article will describe the results of more recent research designed to relate broad-scale features of the 700-mb circulation to concomitant precipitation over the entire United States by a relatively simple and, where possible, objective method.

Monthly mean maps were used for this study because of the increasing emphasis on forecasts for a month in advance. In addition, there was a long period of record for these monthly means, which have the advantage of averaging over a length of time sufficient to make unnecessary any consideration of the initial state. Interpretation of monthly mean 700-mb patterns in terms of precipitation appears quite difficult since the maps often present flatter wave systems with weaker flow and contour curvature than usually observed on 5-day means. Nevertheless, rather small differences in pattern seem to be reflected in the precipitation amounts.

In order that the reader may have a more definite idea of the nature of the problem, a 700-mb monthly mean map of moderate complexity is shown in Fig. 1. This month (February, 1950) was a period of transition during which the trough in the United States sheared, with the higher latitude portion weakening and making rapid eastward progress while the ridge in western North America developed. The corresponding monthly precipitation totals for the United States, expressed in terms of light, moderate, and heavy, are shown in Fig. 2. The problem is to devise a system which will evaluate patterns of this general type in terms of the precipitation class to be expected; the system should help explain such features as the heavy precipitation in the anticyclonic curvature of the ridge in the Northwest, the abrupt transition from heavy to light in the Southeast, and the heavy precipitation through Nebraska and Iowa behind the trough.

An effective tool for interpreting flat patterns such as these is the pattern of the departures from normal of 700-mb height (indicated by the dashed lines on Fig. 1). The construction of these height anomaly fields and their use in temperature forecasting has been explained by Martin earlier in this series. It frequently happens that, even when the trough-ridge system indicated by the contours on the mean chart is poorly defined, well-marked patterns of height departure from normal are evident. They are commonly used in the same sense that one uses high and low pressure centers, that is, a marked center of positive height anomaly indicates a tendency for stronger than normal anticyclonic activity beneath it and suppression of precipitation, particularly on the eastern side in the northerly component of flow, and conversely for the centers of negative anomaly.

The data available for this study included 13 winters of monthly mean 700-mb maps with their associated height anomalies and charts of total precipitation. The country was divided into 21 reasonably homogeneous climatological areas (Fig. 3), and the precipitation in each area for each of the 39 months was classified as heavy, moderate, or light if one of these classes dominated the area. When this was not the case, a combination of classes was used. The

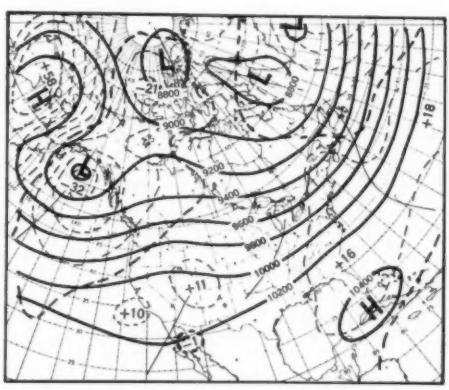


Fig. 1. The mean 700-mb chart for January 28 to February 26, 1950. Contours at 200-foot intervals are shown by solid lines, 700-mb height departures from normal at 100-foot intervals by dashed lines, with the zero isopleth heavier. Contours are labeled in feet and departures from normal centers in tens of feet. Minimum latitude trough locations are shown by light solid lines.

object was to find for each area discriminating parameters (preferably in terms of the departure from normal chart) which incorporated the physical factors of moisture supply and vertical motion and to demonstrate that variations in these parameters were uniquely associated with that area's precipitation.

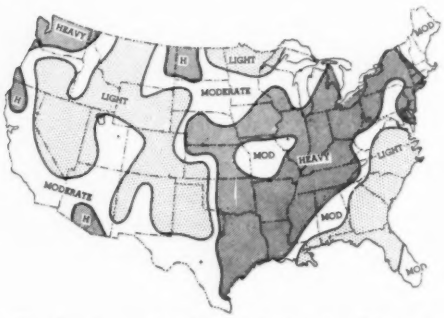


Fig. 2. Accumulated precipitation for February 1-28, 1950, with each class, light, moderate, or heavy, having an equal probability of occurrence.

In view of the limited number of cases (39) available, rigid adherence to the composite map technique used by Martin (see first three articles of this series) and the establishment of "wet" and "dry" patterns was impracticable. However, a modified approach was used which entailed the subjective study of the extreme heavy and light maps as related to the monthly contours and their anomalies at 700 mb. The two parameters which best expressed the differences between the two extremes were tabulated for each case and used as co-ordinates in plotting the graphs upon which the areas occupied by distinct precipitation classes were then delineated. When a third parameter could be shown to improve the results significantly, it was incorporated into the graphs. This procedure and its results will be illustrated by examples.

In eastern portions of the United States, the effective factors usually included a measure of the trough position: the longitude of the 700-mb trough line at 35° or 40° north. This factor is most closely related to Klein's position parameter and his schematic model. The height anomaly in the trough was also found useful. A graph illustrating the relationship of these factors to the precipitation over the upper Mississippi Valley (Area 13 of Fig. 3) is presented in Fig. 4. The mean longitude of Area 13 is approximately 93° west, the vertical axis in Fig. 4. All points to the left of this axis represent cases in which the monthly mean trough was west of the area (exact location indicated on the horizontal axis). The other parameter (indicated on the vertical axis) is the height (or pressure) anomaly where the trough crosses 35° north. This is an index of the depth of the trough, and it is usually related to the intensity of the cyclonic activity making up the trough as well as to the curvature and amplitude of the upper-level wave system.

It can be seen from Fig. 4 that the light precipitation cases occur when the trough is east of the area. This situation is generally associated with the presence of dry northwest winds over the area. Conversely, a deep trough to the west of the area leads to heavy precipitation, and the heavy cases tend to group in the lower left-hand quadrant of the graph. These conclusions are obviously in agreement with Klein's model; the advantage in using the graph lies in its objectivity and its definition of the variation in the precipitation as the trough assumes different depths and orientations.

The separation into the simple classes indicated by the analysis is far from perfect. Some improvement was noted, however, by using a third parameter which measured the departure from normal of the southerly flow at 40° north between 105° west and 90° west. Examination

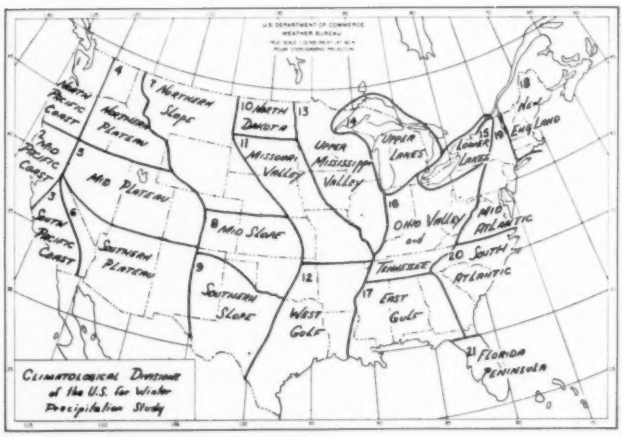


Fig. 3. Twenty-one climatological divisions of the United States, each approximately homogeneous in weather characteristics, based in part on the climatic divisions as given in the *Monthly Weather Review*.

revealed that the stronger this southerly flow the greater the precipitation when the other two factors were constant. For instance, if the trough crosses the 35th parallel at 94° west and has a height anomaly at that point of −175 feet, it will normally be accompanied by heavy precipitation over the upper Mississippi Valley. But if the southerly flow is weaker than normal, the precipitation is more likely to be moderate. From observations of the effect of variations in the southerly flow over different areas of the graph, several supplementary conditions have been noted in the legend for Fig. 4 which amend the graphical separation. In a test on three winters of independent observed data, objective use of this graph led to a correct forecast for 71 per cent of the points which could possibly have been predicted correctly by a one-class areal forecast.

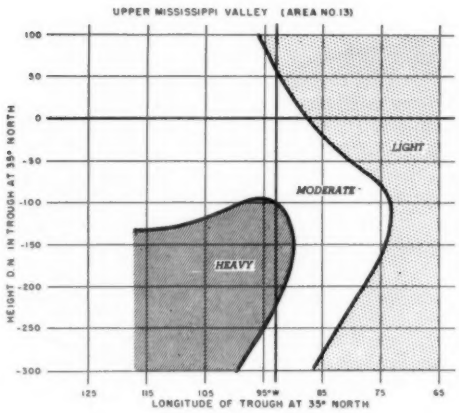
Graphs similar to Fig. 4 were made for most of the areas in the eastern United States. The two primary parameters were much the same, involving trough location and intensity. The third parameter often differed from one region to the next, but usually incorporated some measure of the southerly flow into the area concerned. The efficacy of these devices was not the same in all these regions and a third parameter was not always materially helpful. On the average, their effectiveness in separating the most likely classes was about that represented by the graph for the upper Mississippi Valley.

The most notable exception (in the East) to this approach was in the New England region. It was found that heavy precipitation could occur here not only with a deep trough reasonably close to the west but also with a major trough off the coast. This happens when a low latitude trough in the lower Mississippi Valley brings up warm moist air, and a pattern of confluence between this and the colder polar air results in heavy precipitation over New England. These features were combined in a slightly different graphical fashion but with about the same effectiveness.

In western sections of the country, particularly the Northwest, the absence of troughs on the monthly mean 700-mb charts and the presence of mountain barriers make it inadvisable to use Klein's precipitation model without considerable modification. Instead the more promising factors include:

1. A measure of the intensity of flow of moist Pacific air over the mountain barriers.
2. Indications of strong or frequent cyclonic passages, usually from contour spacing and departures from normal (related to 1).
3. Curvature of upper-air contours.
4. Confluence, generally indicated by convergence of upper-level contours over the area.

In the southwestern portions of the United States, troughs on monthly mean maps are much more frequent, so that a limited use of the pre-



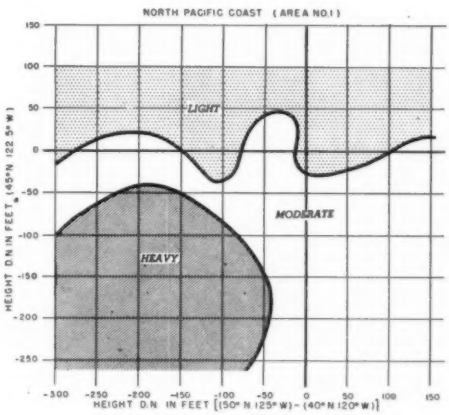


Fig. 4 (left). Graphical separation of monthly winter precipitation for Area 13. The ordinate is a measure of the depth of the trough at 35° north. A third parameter (not shown on the graph) is the departure from normal of the southerly flow measured by the difference of the height departures from normal at 40° north, 105° west, minus those at 40° north, 90° west. This difference is used to change the indications of the graph from light to moderate when the difference is negative; from heavy to moderate when the difference is greater than +35 feet.

Fig. 5 (right). Graphical separation of monthly winter precipitation for Area 1. The abscissa measures the departure from normal of the southwesterly flow at 700 mb and the ordinate indicates the mean height departure from normal over the central portion of this area. The southwesterly flow increases in strength from the axis to the left and falls from near to farther below normal strength going from the axis toward the right.

cipitation model is possible when special cognizance is taken of the four factors listed above.

An illustration of the problem in the western portions of the United States is shown in the graph (Fig. 5) for the north Pacific Coast (Area 1, Fig. 3). This region is adjacent to its principal moisture source and contains pronounced mountain barriers. As a result, the precipitation may be either cyclonically induced or due to orographic ascent. The horizontal co-ordinate of Fig. 5 is the departure from normal of the strength of the southwesterly wind across the area. The stronger the southwest wind, the farther the point falls to the left on the diagram. A strong southwest wind usually brings moist Pacific air into the area and forces it to ascend the coastal range and the Cascades; this augments the normal tendency for convergence with southerly components of flow. On the other hand, increasing northeasterly winds bring intrusions of dry, cold, continental air from southwestern Canada with considerable downslope motion. The departure from normal of the 700-mb height in the center of the area is plotted on the vertical axis of this graph. Presumably this furnishes an index of the frequency and intensity of frontal and cyclonic passages. It may be noted that light precipitation rarely occurs when the pressure (or height) at this point is below normal, while no heavy cases occur when it is above normal. In the test previously mentioned, the graph for the north Pacific Coast led to a correct prognosis for 74 per cent of points which could be forecast correctly by a one-class areal forecast.

Since the graphs constructed were limited to two or three parameters, it was expedient to incorporate the effects of both vertical motion and moisture in each parameter wherever possible. For instance, in the Pacific Northwest a southwest flow measures both of the important factors; in the upper Mississippi Valley these factors are dependent upon the location, intensity, and profile of the trough-ridge system. Over the mid-plateau the 700-mb contour curvature was considered, and for the northern slope and North Dakota a measure of confluence was introduced.

The graphical approach described has led to success in all areas of the United States. It appears that the precipitation regimes are readily explainable, hence suitable for such simple graphical representation, where the normal amounts of precipitation are large and where orographic features are either quite dominant or of very minor importance. Thus, moderately successful objective methods have been developed for the areas numbered 1, 2, 4, 10, 13, 16, 17, 18, 19, 21, and conditional objective methods for 12 and 15. For the remaining areas a forecasting guide was prepared. This outlined what appeared to be the major circulation features accompanying the occurrence of heavy and light precipitation for each area. These observations can be qualitatively applied to the prognostic charts.

Returning to Figs. 1 and 2, we shall discuss the precipitation pattern and its relation to the mean upper-level flow in terms of these techniques. For the upper Mississippi Valley, Fig. 4 indicates moderate is the best forecast; however, the cyclonic curvature is most marked near the southern sections of the area and the trough has been advancing eastward. Hence, the southern sections may well expect heavy and northern sections moderate to light. The north Pacific Coast graph, Fig. 5, suggests moderate as the best forecast. This is adequate for the Oregon coast, but the southwesterly flow intensifies slightly towards the north and heights are increasingly below normal over the Washington coast northwestward. The sensitivity of the region to this height departure from normal parameter has already been mentioned, and heavy must be expected over the northern sections of this area. Other features worthy of mention include: the weak trough in the far Southwest with its attendant precipitation, the light under the plateau ridge extending (partly due to foehn action) east of the divide over most of the slope of the Rockies, the heaviest precipitation amounts in the central Mississippi and Ohio Valleys just east of the trough with stronger than normal southerly components, and light in the Southeast under the weak contour ridge but rather well-marked center of positive height anomaly.

While the study and interpretation of monthly upper-level patterns is relatively new, it can be seen that the basic concepts which prove effective are merely modifications of those factors which have been tested and used in daily and 5-day patterns. The results of this study have in turn been helpful in focusing attention on the more common modifications and have facilitated their interpretation on occasion of their appearance on 5-day means.

In the next and concluding article in this series, we shall return to the shorter term circulations and present some composite maps and forecast graphs.

LIGHTNING DANGER

According to F. Barrows Colton, in the **National Geographic Magazine** for June, a person has one chance in 365,000 of being struck by lightning in the United States in a year, for 400 people are killed annually by lightning and about 1,500 more are injured.

One of the safest places to be is in an all-steel closed automobile, for the steel body will conduct the current away from the occupants. This is also true of all-metal airplanes, and there is no known case of lightning directly causing an airplane accident.

Lightning manufactures out of the air about 100 million tons of valuable nitrogen fertilizer every year. Fertilizer manufacturers, using the same electric-spark method, take nitrogen from the air more efficiently than does nature's haphazard way.

WORKSHOP FOR WEATHERMEN

CONDUCTED BY CHARLES A. LAIRD

How to Construct A Miniature Tornado

AN EARLY weather researcher and experimenter was William Henry Dines. Some of the weather instruments invented by him are in regular use in weather stations. The Dines pressure tube anemometer is world famous. Here is an experiment described in one of Dines' papers which should be of interest to amateur weathermen. It is an apparatus for producing a miniature tornado or waterspout—exceedingly small when compared to the real thing, but very lifelike in appearance.

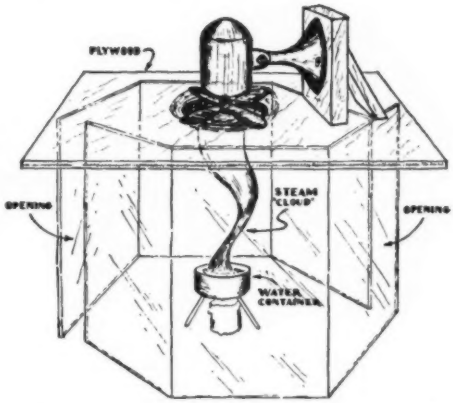
Take six pieces of ordinary window glass and arrange them in two sets of three each. Their size is not too critical, about 1½ by 2 feet will do. You may fasten them together with string or by using tape at the adjacent edges. The two sets should be placed on a table in the manner shown in the drawing. The opposite edges of the two sets of three glass panels should not meet, but should be offset laterally as shown. These spaces are for the entry of air into the chamber for reasons described below.

In the center of the enclosed space, place a small container of water, such as an old pan or tin can. You can make a small tripod for support by bending stiff wire into the proper shape. Place a Bunsen burner, alcohol lamp or some other heat source under the container. A small Sterno stove will serve very well.

Lay a piece of ¼″ or ½″ plywood on top of the panels, large enough to cover the glass-enclosed space. This panel should have a 6″ or 7″ hole in its center. A fan to draw air upward through the hole is mounted on the plywood panel, as shown in the drawing. The motor should be reversed or the blades bent so air flows in the upward direction. If you cannot obtain a fan, make a propeller arrangement and drive it with a pulley and hand crank.

When water is boiled in the container, a cloud will rise, being drawn upward at a speed controlled by the suction produced by the fan. And air coming into the glass-enclosed space through the transverse openings will produce a rotary motion. The whirling steam cloud has all the appearance of a tornado funnel. You can vary its size and whirling motion by changing the openings between the two sets of glass panels and by using different fan speeds. Interesting observations may be made by throwing small pieces of cotton or paper through the air spaces and watching their motion. Note that the cloud column is distinctly hollow. It is interesting to watch the funnel disappear and form again when the fan speed is abruptly changed.

The amateur weatherman setting up this apparatus should consult some of the meteorological treatises and study photographs of tornado and waterspout activity to add to the value of the experiment.



The apparatus for producing a miniature tornado or waterspout.

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THE WEATHER BUREAU'S FIRE-WEATHER SERVICE

(Continued from page 102)

Washington Forest Fire Association, in its 37th annual report, states:

"We have co-operating with us the United States Weather Bureau, giving us advance information as to approaching dangerous fire-weather conditions. Logging operators now know that fires originating at such times become almost instantly beyond control. This warning service has become the mainspring of forest protection and prevention in the logging camps of western Washington. To this one step can be laid the decreased losses which heretofore were suffered by the industry. . . . The co-operation of the fire-weather service is one of the most valued assets in the work of fire protection."

One ranger in North Carolina reported that the fire-weather forecasts saved 2,000 acres, averting $16,000 damage on his district during the spring of 1949. The state forester of Virginia estimated that 344 fires were prevented in one season. In West Virginia, a forester pointed out that 2,650 acres were saved in one day by applying the forecasts.

In Montana, where lightning alone causes over 1,100 forest fires annually, $90,000 damage was prevented in one year. In addition, 15,000 man days of labor were made available for productive work — without fire-weather service this time would have had to be spent in fire fighting. In Oregon, $10,000 damage was prevented on four fires alone.

Weather Bureau employees engaged in providing fire-weather service are aware of their responsibilities, and continuing efforts are directed toward providing forecasts that will be of the greatest assistance to those who are charged with keeping the forests green.

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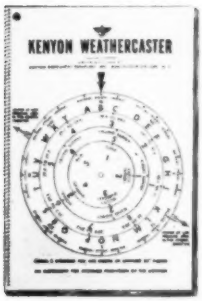
OPEN SEASON ON HURRICANES

(Continued from page 109)

passing north-northwestward out of the state into Georgia during the night of the 6-7. Flooding rains did much damage to roads in the Brooksville area, where 20.41 inches fell, but for the most part the rains were very welcome after much dry weather, and the benefit to citrus interests greatly outweighed any minor wind damage. Unusually heavy rainfall resulted from this storm in a strip from Tampa Bay northeast into the south tip of South Carolina, Savannah recording a total of 16.21 inches in about 75 hours.

Storm VI — September 10-16: This was the farthest out of all the storms, and it behaved just about according to Hoyle, recurving to the northeast without affecting any land areas.

Forecasting Aids



901 WEATHERCASTER — This handy booklet translates current weather conditions into a weather forecast. Four plastic dials are adjusted by the observer to match current conditions. The four elements are: sky condition, barometric tendency, height of the barometer, and wind direction. A key number then enables one to read the appropriate forecast from inner page tables. Size: 6½ x 9 inches. **$5.00**

901

902 WEATHER GUIDE — The basic concept of the Weather Guide is that the major factors determining short period weather changes are revealed by the cloud formations in the sky and the wind direction on the ground. One merely selects the cloud picture most nearly matching current conditions, sets the wind arrow opposite the cloud picture, and reads off the forecast. The Weather Guide comes in seven models for use in each of seven zones of the United States. Size: 8 x 2 x 1 inches. **$12.50**

902

306-8

306 METEOROLOGICAL BAROMETER—U.S. Weather Bureau type. Contains best-quality movement. Special aneroid cell is temperature compensated. Open-face silver dial has double scale with graduations to 0.02 inch and to one millibar. Adjustable pointer for comparative readings. Overall diameter, 5¼ inches; thickness 2½ inches. Weight 1 lb. 11 oz. For use between sea level and 3,000 feet. **$30.00**

307 METEOROLOGICAL BAROMETER for medium altitudes. Same as #306 but for use between 2,900 and 7,100 feet. **$35.00**

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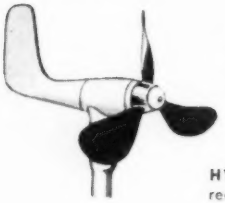
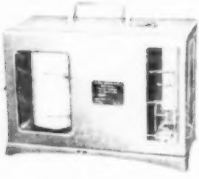


THE AEROVANE* TRANSMITTER—Combines wind speed and direction components in one unit. It consists of a three-bladed molded rotor to measure wind speed, and a streamlined vane for wind direction.

HYGROTHERMOGRAPH—Temperature recorder for temperature and relative humidity—ideal for meteorological stations—particularly well adapted to the requirements of industry in general.



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